

# Statistical Analysis and Experiments in Manual Demining

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## Abstract

*This paper presents the results of experiments and statistical analysis of the performance of manual demining in Afghanistan. Results of probing tests under ideal sandbox conditions are also reported.*

*The results show that probing is unreliable at target depths of more than 7 cm under ideal conditions. While this result has been reported in anecdotal evidence there are few reports of systematic trials to confirm this.*

*Prodding to excavate metal fragments is reliable and much faster than many early reports suggest: a typical average time to recover a 25 mm square, 3mm thick buried fragment in hard ground is 45 - 55 seconds.*

*Statistical analysis matches the experimental data well. Models derived from a large number of minefield clearance records from the Mine Action Centre for Afghanistan suggest that the time needed to detect, locate, mark and excavate each fragment is approximately 1.8 minutes.*

*These results suggest that mechanical vegetation clearance is essential to achieve significant productivity gains from using advanced technology detectors in countries with significant vegetation cover.*

## 1. Introduction

This research aims to improve understanding of the manual landmine clearance process (demining) by modelling clearance time in terms of the factors affecting clearance time and reliability. The paper describes experimental and analysis work performed between 2000 and 2002 that enables us to question some long-held assumptions about manual demining.

Many writers have justified large expenditure on advanced technology detection methods such as ground penetrating radar, nuclear quadrupole resonance, neutron beam irradiation and others by asserting that deminers spend most of their time probing the ground looking for mines and mainly finding metal fragments. It is not unusual to hear about deminers taking up to 20 minutes to locate a single metal fragment.

In 1998 we performed a preliminary analysis of minefield clearance statistics from Afghanistan. This analysis suggested that the average time taken by deminers to find each fragment seemed to be between 1.5

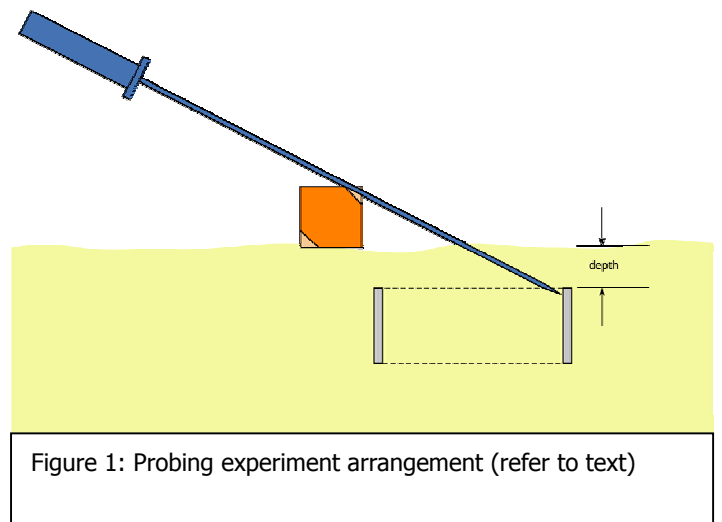


Figure 1: Probing experiment arrangement (refer to text)

and 2.5 minutes (including the time needed to detect and mark the fragment location). In 2000 we decided to conduct a series of simple experiments to obtain some experimental evidence to test this conclusion. We performed large number of simple but tedious experiments. In 2001-2, with the help of students, we performed a much more rigorous analysis of more recent data from Afghanistan. As this paper shows, all this

research supported the original preliminary findings. In summary, the time taken by deminers to find metal fragments was much less than many people had thought previously.

These findings lead us to question the economics of advanced technology detection methods. The overall productivity improvements obtainable may be much less than originally expected, especially in environments where deminers take up to 70% of the time clearing vegetation before they can start using any detectors. In Afghanistan, as our analysis shows, vegetation is not a significant factor in clearance time so the potential for improvement using advanced detection technology is likely to be greater than in other countries.

## 2. Probing Experiments

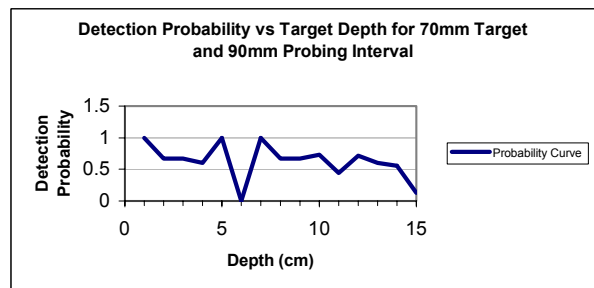
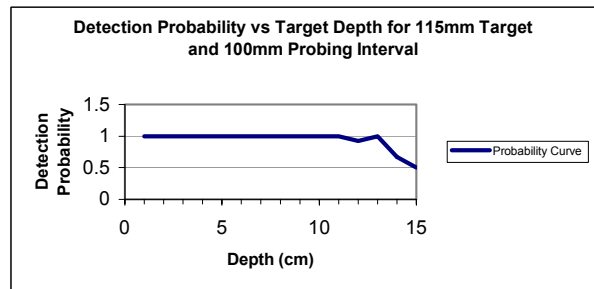
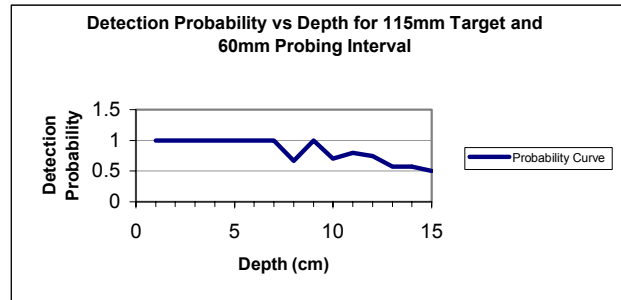
In 2000 we performed a large number of probing experiments under ideal sandbox conditions to determine the best possible results from probing as a method for finding buried blast mines. (Wong 2001) While probing is seldom recommended as a demining method, it is rare to find published experimental data on actual performance.

Simulated mine targets made from plastic rings cut from PVC tubing were carefully inserted into clean beach sand such that no disturbance to the sand could be detected subsequently. The targets were buried in a specially designed random distribution calculated by a computer program. The test area size was approximately 6 square metres. A deminer then used a long, thin, sharp-ended probe in a prescribed pattern with 30 degree insertion angle with the spacing determined by different wooden guide bars. The probe rod was 440 mm long, sufficient to detect a target at a depth of 150 mm while resting on the 50 mm square cross section guide bar.

In all, 72 tests were conducted over a four month period using different target sizes and probe point spacing combinations. The test design was “single-blind”: the person supervising the tests had inserted the targets, but the deminer did not know the number of targets present or their locations. Every test was different: targets were laid with different average densities and depth distributions. Representative results for detection probability are shown below.

The results of these tests showed that even under ideal conditions, probing was not a reliable method for finding

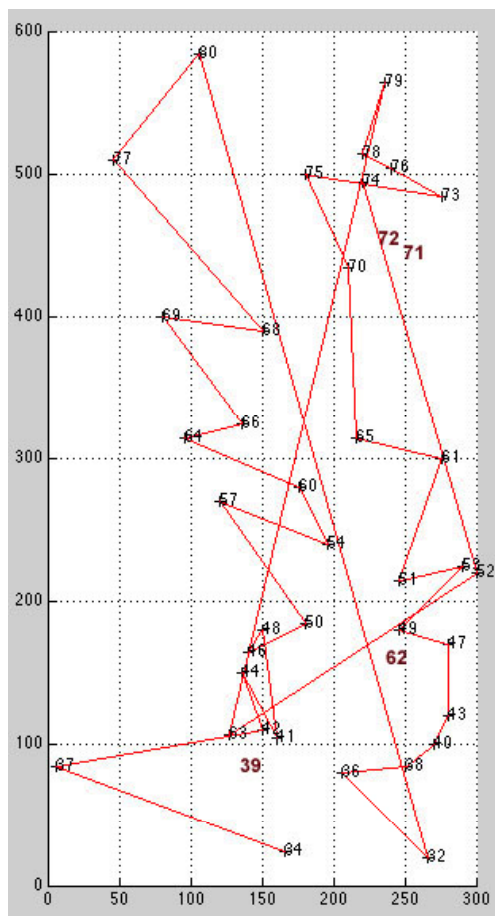
buried targets at depths of greater than about 8-10 cm, even though the probe was long enough and the sand soft enough to penetrate 15 cm below the surface. The significance of these test results is that they were conducted under ideal conditions: in any field conditions it is very unlikely that the performance would be as good.



Graphs 1-3: Target detection probability from probing tests. Note that the probe point spacing exceeded the target diameter in the third graph leading to low detection probability as expected.

These tests revealed that probing is not a reliable method for finding buried targets at a depth of more than 7 centimetres, even under ideal carefully controlled conditions.

## 3. Metal Detection and Prodding



## Experiments

The second series of tests were conducted to determine performance parameters relevant to manual demining in Afghanistan. The normal SOP requires that deminers locate targets with a metal detector and then excavate the suspect target (prodding) until either a mine is sighted or the metal fragment is recovered and removed. (Trevelyan 2001)

Afghan deminers selected three test areas in Islamabad where they considered ground conditions to be representative of typical Afghanistan conditions. We conducted a series of manual demining experiments in which small standardized targets were inserted into the ground using a technique that results in almost no ground disturbance. The targets were 25 mm square pieces of mild steel 3mm thick with a stamped identification number. The targets were buried in a specially designed random distribution calculated by a computer program. It was not possible for deminers to see or feel where targets

had been buried before each test. Deminers used Schiebel AN-19 detectors to locate the targets using standard SOP's and then excavate the targets using prodders and standard procedures. We recorded the time required to locate each target, mark its position and the time needed to locate the target by normal prodding. The average total time turned out to be about 1.5 minutes per target which agrees well with results from a statistical analysis of

Figure 3 Typical record of manual demining experiment indicating the sequence of targets found. This easily reveals mistakes by deminers. In this test, targets 39, 62, 71 and 72 were missed

actual clearance time performance over about 2000 manual demining tasks in Afghanistan, described in the third part of the paper.

As in the probing tests reported above, a large number of tests were conducted. Approximately 70 trials were run, in which between 30 and 200 targets were placed in the test area. Any targets missed on one test were manually removed and the ground was restored to normal levels of compaction before conducting further tests on the same ground.

The ground was hard for nearly all the tests conducted. The target insertion tool was a steel bar 15 mm square, tapered to a slot at the bottom end in which the targets were placed. 20 to 30 blows with a 5 kg hammer were needed to drive the tool into the ground to insert targets at



Figure 2 Measuring hole left by deminer after metal detection and prodding to remove metal fragment

the maximum depth (18 cm).

After each test we produced a map showing the locations of the targets with a line joining the target

positions to graphically show the sequence of targets found. This enabled us to make observations on the reasons for missing certain targets. For example, in figure 3, targets 71 and 72 were missed because they co-incided with the change-over between two deminers at a rest break.

We also recorded the size of the hole created during the prodding for each target (see figure 4). The data recorded showed that the hole volume was closely related to prodding time as expected. The average time required to detect and mark each target was 25 seconds and the time to excavate each target was 45 – 55 secs average. The relatively short time was surprising given the hardness of the ground and the difficulty of visually seeing the targets which had become coated in fine dusty clay and hence the same colour as the ground.

#### 4. Statistical Analysis of Manual Demining Performance Database

The Mine Action Centre for Afghanistan (under the UN umbrella) maintains a database of the minefields cleared in Afghanistan since 1990. The goal of this project was to use this database to construct a statistical model for clearance time for manual demining. This was building on initial work done by Trevelyan (1997, 2001). Thus the aim was to be able to predict clearance time for a given minefield, given the factors affecting clearance time, such as area, number of metal fragments, ground hardness, vegetation type and density, and any other factors available in the database.

The MACA database has been compiled from daily field reports submitted by all demining agencies in Afghanistan. The format of data recording has been reasonably consistent since 1993. The database combines level 1 and level 2 survey information with the clearance data. It defines the position and boundary of each minefield, original information sources, land use type, surface category, area reduction during survey operations, which agencies surveyed and cleared the minefield, what was found (fragments, anti-personnel mines, anti-tank mines, UXO), the area surveyed, area after survey (area reduction) and area cleared.

The Mine Action Centre for Afghanistan (MACA) database provided the field data for analysis. Bartley

(2002), (see also Bartley and Trevelyan 2003) provides a rigorous statistical analysis of the data and derived the following models.

##### 4.1. Model with all statistically significant parameters

The final model fitted to the data (the ‘data driven model’) contained all parameters determined to be statistically significant (at  $\alpha=0.05$ ). It was based on 635 of the original 710 points, the most influential having been removed in order that the model represent most of the data, rather than be shaped by a small number of highly influential points. The residuals vs. fits and the residuals vs. Cook’s distance plots show that the residuals have constant error variance, and there are no obviously extreme Cook’s distances. Although the AP term has  $p=0.063$ , this is close enough to  $\alpha=0.05$  to include. The final transformed model exhibits no lack of fit, and obeys the assumptions that the error is identically and independently normally distributed. Thus the final model may be presented as:

$$\ln(CLEARTIME) = b_0 + b_1 \ln(FRAGS) + b_2 (AREA)^{0.5} + b_3 \ln(AP+1) \dots(1)$$

(See appendix for details, table 1 for coefficient values)

##### 4.2. Simplified WLS model

The most basic descriptive model was simply to fit the model for clearance time in terms of fragments and area. It took four iterations to get to a model that had a reasonable consistency in influential points, and the final data set had 660 of the original 710 records:

$$CLEARTIME = b_0 + b_1.FRAGS + b_2.AREA \dots(2)$$

Table 3 (appendix) shows that  $b_1$ , the 'Per Fragment Allowance' is about  $1.8 \pm 0.1$  bpm/frag. This is roughly in agreement with the simulated field experiments that have suggested that detection and marking time is around 25 – 35 seconds, with 45 seconds for excavation – 1.2-1.3 minutes total (Trevelyan 2001). The fact that the experimental value is lower is possibly due to conditions being more controlled and ideal. In the absence of fragments, the land is cleared at a rate of about  $0.45 \pm 0.06$

bpmin/sqm. The meaning of the constant is a little uncertain – it may be interpreted as the constant overhead incurred by clearing any minefield, or possibly a correction for small minefields, but is quite low at  $7.3 \pm 2.3$  tmhr per minefield, compared to the median clearance time of 87.5 tmhr.

The resulting models suggest that the number of fragments was the single most important factor affecting clearance time, followed by minefield area. The effects of the different types of vegetation, land use, and surface, and different demining agencies, were also modelled. The result is a number of models suitable for predictive and descriptive purposes. These results confirmed earlier less rigorous research, and extended it in terms of thoroughness, statistical validity, and inclusion of new variables.

By providing a quantitative understanding of manual clearance, these models could improve clearance time predictions, give insight into process improvements, and provide quantitative tools to evaluate the performance improvements that might be obtained from new detection technologies or alternative demining procedures. Analysis also revealed significant differences between demining organization performance that indicates a need for deeper investigation of field practices. (Bartley 2002).

## 5. Conclusions

The results from the probing experiments indicate that probing, by itself, is not likely to be a reliable method for manual demining. Anecdotal field reports confirm this.

The results of the prodding and metal detection experiments showed that the average *additional* time needed for a deminer to locate a fragment and remove it by prodding was about 1.3 minutes, with the first 35 – 45 seconds spent in locating the target and marking its position. This compares well with analysis of field data from Afghanistan (1.8 minutes). These times are much shorter than the 10 to 20 minutes per fragment that is often reported in the literature from anecdotal evidence. Also, given that the time to detect and locate the target with a detector is a significant proportion of this, the improvements possible with advanced detectors using radar and NQR are likely to be modest at best. This is because they also rely on metal detection for the initial location of targets for analysis.

Unlike most countries, the effect of vegetation on manual demining clearance times in Afghanistan is relatively small. In any country where vegetation clearance is a significant part of the demining process, the improvement from using advanced technology detectors is likely to be very small.

## 6. References

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Afghanistan. The minefield clearance data was kindly provided by Mine Action Centre for Afghanistan, whose

staff provided many hours of valuable discussions and assistance.

## Appendix

### Data Driven Model

$$\ln(CLEARTIME) = b_0 + b_1 \ln(FRAGS) + b_2 (AREA)^{0.5} + b_3 \ln(AP+1) \dots(1)$$

Variable / parameter	Definition
<i>AP</i>	Number of AP mines found in a minefield.
<i>AREA</i>	Area, in sqm (m <sup>2</sup> ).
<i>AT</i>	Number of AT mines found in a minefield.
<i>CLEARTIME</i>	Clearance time, in team hours.
<i>FRAG</i>	Number of metal fragments found in minefield.
<i>PFA</i>	Per Fragment Allowance, in bmin/frag or tmhr/frag (see Glossary).
<i>TPA</i>	Time Per unit Area, in bmin/sqm or tmhr/sqm (see Glossary).
<i>u<sub>i</sub></i>	Represents random disturbance.
<i>UXO</i>	Number of pieces of UXO found in a minefield.

Table 1 Model variables and parameters

Parameter			b <sub>0</sub>	b <sub>1</sub>	b <sub>2</sub>	b <sub>3</sub>
(R <sup>2</sup> =85.2%)			Constant (lnTmhr)	Fragment Slope (lnTmhr/lnFrag)	Area slope (lnTmhr/sqrtSqm)	AP (lnTmhr/ln(AP+1))
<b>Base figure</b>			-1.77	0.536	0.00345	0.0107
<b>Additional effects</b>	Land use	<b>Grazing,</b> Irrigation, Road Agricultural Residential		0.022	0.00067	
	Has UXO	No Yes	0.13			
	Hard surface	No Yes		0.014		
	Vegetation	<b>Bushes,</b> Grass, None Prickly bushes Trees		0.013	0.00054	
	Demining agency	ATC DAFA	0.09			
<b>Total</b>						0.0107

Table 2 Data-driven model parameters – sum column to calculate parameters

### Simplified WLS model

$$CLEARTIME = b_0 + b_1.FRAGS + b_2.AREA \dots(2)$$

<b>General</b>			n (number of points)	710	
			Num pts removed (influential or outliers)	50	
			s	1.20	
			R <sup>2</sup>	77.5%	
<b>Model Parameters</b>	<b>Constant</b>	b0	tmhr	Value	7.33
				+/- 95% CI	2.32
	<b>Per fragment allowance (PFA)</b>	b1	tmhr/frag	Value	0.00247
				+/- 95% CI	0.00013
			bpmin/frag	Value	1.78
				+/- 95% CI	0.09
	<b>Time per unit ara (TPA)</b>	b2	tmhr/sqm	Value	0.000619
				+/- 95% CI	0.000086
bpmin/sqm			Value	0.445	
			+/- 95% CI	0.062	

Table 3 WLS Model parameters

\*The conversion from team hours (tmhr) to breaching party minutes (bpm) is done by multiplying by 12 breaching parties / team and 60 minutes / hour.